THE ANNALS

AND

MAGAZINE OF NATURAL HISTORY.

[FOURTH SERIES.]

No. 47. NOVEMBER 1871.

XXXVI.—*On the Evidence of a Glacial Epoch at the Equator.*

By James Orton, of Poughkeepsie, N. Y.*

The valley of the Amazon is highly interesting to the geologist, from its vast extent and its disputed origin. Probably no other region on the globe, of equal area, has such a remarkably uniform character: from the Andes to the Atlantic, and from the falls of the Madeira to the Orinoco, scarcely any thing is visible but clays and sandstones †. Professor Agassiz was the first geologist of eminence to explore any considerable part of the formation. He ascended the river to Tabatinga (1500 miles in a straight line); and he has well described the successive beds, of which he distinguishes ten. The chief, in the order of superposition, are:—coarse sand, laminated clays of divers colours, ferruginous sandstone, and an unstratified sandy clay; of these, the argillaceous portion is the most important, as it is the most extensive, the sandstone being reduced to isolated hills by denudation. The clays generally are very fine in texture, and without a pebble: they contain a large percentage of iron, but no trace of lime; there are, however, calcareous concretions, nodular or stalactiform, strikingly similar to the marly concretions noticed by Darwin in the Pampean mud. The argillaceous deposits are more conspicuous on the Upper Amazon, and the sandstones on the Lower. The whole formation dips gently to the east, and its total thickness is about 800 feet.

Professor Agassiz considers the valley a cretaceous basin, filled with glacial drift—in other words, that all these clays

* From a separate impression communicated by the Author.

† Professor Agassiz speaks of this clay formation as stretching over a surface more than three thousand miles in length; but he is evidently led astray by the length of the Amazon, with all its windings. The width of the continent at the equator is only 2,100 miles.

and sandstones were deposited underneath a gigantic glacier, which descended from the Andes, grinding into fine powder the materials between it and the solid rock, and leaving an immense moraine across the mouth of the valley. To this theory we make the following objections:—

1. The theory is short of positive proof where we need the most unquestionable evidence. The confession is made that "the direct traces of glaciers, as seen in other countries, are wanting in Brazil." There is not a trace of furrows, striæ, or polished surfaces*. The answer that the rocks are so friable, and disintegration in the tropics so rapid, as to render their discovery hopeless, is not entirely satisfactory. The granitoid rocks which border the valley, and the schists and porphyries on the slope of the Andes, ought to preserve some marks of the glaciation†. The pot-holes in the gneiss plains of Bahia, supposed by Hartt to have been formed by glacial cascades, are "exceedingly well preserved, and have smooth sides;" while all the ploughings and planings of the gigantic glacier over the same rock have been utterly erased by disintegration! The stone structures of Brazil endure remarkably well, while the granite of Quebec exfoliates so rapidly in winter that oil is used to protect the buildings; yet there is no lack of striæ in Canada.

Boulders occur only along the eastern region; none have been observed in the great interior basin. This is a strange inversion: if a continental glacier moved down the Andes to the Atlantic, we would naturally look for porphyritic boulders scattered over the valley, and dwindling in number and size as we near Pará. We are suspicious, also, that these so-called boulders have not travelled. The only genuine erratics seen by Professor Agassiz were found on the northern flank of Ererê; all the others turn out to be "boulders of decomposition." The boulders of Tijuca, in the Rio Province, described by Hartt, were not far-fetched; the majority are of gneiss on gneiss: still they may have been the work of local glaciers. The Ererê erratics are hornblendic and without scratches;

* Professor Hartt likewise acknowledges, "I have nowhere seen either polished or striated rocks."

† The eminent explorer Dr. Spruce describes the Casiquiari Region as "one great sheet of granite and gneiss. There is nowhere any continuous range of mountains or plateau; and, except towards its borders, the granite has been entirely denuded of the stratified rocks that once overlay it, and is now either naked or else overspread in some places with a thin covering of white sand, and in others (chiefly flats, hollows, and rifts) with a thick deposit of the fertile 'terra roxa,' or red loam (decomposed gneiss, mica-schist, &c.), which I have supposed to be lacustrine, but Professor Agassiz says is glacial drift."

the lack of striation, however, is no proof that they are not true boulders.

To complete the glacial picture, it is asserted that a gigantic moraine stretched across the mouth of the valley—though, as Dr. Newberry says, "a moraine can hardly be formed by a glacier, except where there are cliffs and pinnacles along its course;" and as the absence of glacial inscriptions is attributed to disintegration, so it has been found convenient to say that this morainic wall must be looked for in the depths of the Atlantic*. It is worthy of remark, moreover, that fiords, which are conterminous with the drift of high latitudes, are absent from equatorial coasts. Thus we are called upon to believe in the existence of a tropical glacier, 2000 miles in length, moving "for hundreds of thousands of years" over the continent, upon evidence which is singularly defective.

2. We object to the theory because the formation contains Tertiary shells. Previously to the expedition of the writer across the continent in 1867, the vast clay-beds along the Great River had not yielded a single fossil. In the words of Professor Agassiz, "Tertiary deposits have never been observed in any part of the Amazonian basin." And it was on this negative evidence mainly that the distinguished naturalist hazarded the conjecture that the formation was drift. But the banks of the Upper Amazon prove to be highly fossiliferous. At the confluence of the Ambiyacu with the Marañon stands the village of Pebas, about two hundred miles west of Tabatinga, long. 72°. The site is a level tract, about fifty feet above the river; and the formation is wholly of those peculiar variegated clays which we traced far up the Napo, and are continuous with the Tabatinga beds and with those on the Lower Amazon, where they are overlain by sandstone. Imbedded in these clays, several feet below the surface, and incontestably *in situ*, we discovered numerous small shells. They were examined by Mr. Gabb, of Philadelphia, who published† the following species:—*Turbonilla minuscula*, n. sp.; *Neritina pupa*, Linn.; *Mesalia Ortoni*, n. sp.; *Tellina amazonensis*, n. sp.; *Pachydon obliquus*, n. sp.; *P. tenuis*, n. sp.

Before leaving Pebas, we engaged Mr. Hauxwell, the experienced English collector, residing at that place, to search

* It seems to us that if "the waters of the lake were suddenly released," they would have exerted the most denuding force near the outlet; yet along the Lower Amazon we find vast remnants of the sandstone series, as those of Ereré, Obidos, and Almeyrim, while further west the waters seem to have made a clean sweep of it. No table-topped hills like Almeyrim are seen west of Manáos.

† Amer. Journ. Conch. vol. iv. p. 167.

for other localities. In February 1870 he reported a large deposit on the south side of the Marañon, thirty miles below Pebas, at Pichaua, just west of Cochaquinas *. The shells were larger and more plentiful than at Pebas, but were found in the same layers of red and blue clays, from six to twenty feet beneath the soil. A collection (in quantity about half a bushel) was received in August, and submitted to the eminent palæontologist, T. A. Conrad, Esq. His paper, published in the 'American Journal of Conchology,' Oct. 10, contained many additional species, and corrected some mistakes into which Mr. Gabb had fallen from lack of perfect specimens. The following is a complete list, numbered in the order of abundance, No. 1 being the most numerous †:—

Gasteropods.	Conchifers.
5. Isæa (Mesalia) Ortoni, *Gabb.*	3. Pachydon tenuis, *Gabb.*
12. —— (——) lintea, *Conrad.*	2. —— carinatus, *Conrad.*
9. Liris laqueata, *Conrad.*	1. —— obliquus, *Gabb.*
8. Ebora crassilabra, *Conrad.*	6. —— erectus, *Conrad.*
14. —— bella, *Conrad.*	7. —— cuneatus, *Conrad.*
15. Hemisinus sulcatus, *Conrad.*	11. —— ovatus, *Conrad.*
13. Dyris gracilis, *Conrad.*	10. —— altus, *Conrad.*
4. Neritina Ortoni, *Conrad.*	17. Fragments of a singular bivalve, probably allied to *Mülleria.*
16. Bulimus linteus, *Conrad.*	

The *Neritina*, which Gabb made identical with the living *N. pupa*, proves to be a new species. The *Isæa Ortoni* is accompanied by an immense number of small, delicate shells, which Conrad considers its young. He thinks the genus is related to *Tricula*. *Liris* and *Dyris* probably belong to the *Melaniidæ*; and *Ebora* is presumed to be a freshwater genus. Of *Hemisinus* and *Bulimus* there was but one specimen each. *Pachydon* ‡ is the most important genus, the collection furnishing seven distinct species. Conrad makes it one of the Corbulidæ, though its spiral beaks are in marked contrast with those of *Corbula*. Some of the species attained con-

* Mr. Hauxwell writes that he has found similar shell-beds on the north side of the Marañon, about a mile inland, both east and west of Pebas, and also at Maucallacta.

† The type series is now in the New-York State Geological cabinet.

‡ As this name is too near *Pachyodon*, Conrad suggests *Anisothyris*. It had an internal cartilage in a pit behind the tooth of the right valve, exactly as in *Corbula*; and Meek is inclined to consider them identical. The only shell observed by Darwin in the Pampean formation was *Azara labiata*, D'Orb., one of the living Corbulidæ. It has no spiral beak. Several species of *Azara* (*Patarnomya*) live in the brackish parts of the Amazon. *Corbulæ* were abundant in the early Tertiary. See Ann. Nat. Hist. for Jan. and Feb. 1871.

siderable size, particularly *tenuis* and *erectus*; a specimen of the latter before us measures 2 by 2¼ inches, and is packed with clay crowded with *P. obliquus*. All the specimens are remarkably perfect, except *Bulimus* and the unknown bivalve. The valves of the Pachydons are seldom separated, and scarcely ever broken, and none of the shells show the least abrasion. The *Neritina*, *P. tenuis*, and *P. carinatus* retain the epidermis, the first displaying various patterns of coloured zigzag lines. Many species, as *Isæa lintea*, *Liris laqueata*, and *Dyris gracilis*, are exceedingly delicate, yet perfect. But Agassiz says the Andean glacier must have ploughed the valley-bottom over and over again, grinding all the materials beneath it into a fine powder. How did these shells escape during "the kneading-process the drift has undergone beneath the gigantic ice-plough?" The supposition that they may have been washed in from another locality must be rejected; for they are plainly in place, and none are water-worn. "It seems clear," says Conrad, "that they were not transported from a distance, but lived and died in the vicinity of the spot in which they are found." The shells are filled with the same bluish or drab sandy clay, "holding minute scales of mica, and frequently ferruginous," in which they occur. The Pachydons abound in the indurated and concretionary as well as soft parts of the formation.

Here, then, we have a large collection of shells from localities thirty miles apart, exhibiting seventeen species, all extinct, belonging to nine genera, only three of which have living representatives. The beds, therefore, cannot be later than the Pliocene. There is not one strictly marine genus; Gabb's *Tellina* turns out to be the young of *P. tenuis*. The deposit was probably of brackish-water origin. Only one specimen of the land-shell *Bulimus* was found; and this was about the only one in the collection which appears to have suffered fracture before deposition. The fact that all the parts are so orderly laid down (lignite, clays, and sandstones) points to a quiet formation, and not to a tumultuous flood or debacle. Any subsequent oscillation must have been continental; for the beds are without sign of being unequally tilted or dislocated.

It is quite plain that the drift theory of this formation must be abandoned; but Professor Hartt, to whom science is indebted for many minute and careful observations on the eastern border of Brazil, has propounded a new version. He thinks that the clays and sandstone are very late Tertiary and marine, while the superficial unstratified deposit, covering

like a sheet the whole country (plains, campos, and sierras), is drift, the product of a general glacier*. It is doubtful if even local glaciers, of any great extent, existed on the mountains of Minas when they stood at a higher altitude than at present, for the same reason that glaciers are now absent from the equatorial Andes; but, for arguments already given and to follow, we certainly cannot believe in the existence of a vast glacier stretching from the Andes to the Atlantic.

3. We question the possibility of its formation. At the equator there is little variation of temperature. Pará is noted for its equable climate, varying little from 80°. At the Hacienda, on the slope of Antisana, 13,300 feet, the mean temperature in spring is 42°, summer 38°, autumn 40°, winter 41°. The snow-line on the equatorial mountains is therefore stationary; while the oscillation from summer heat to winter cold, in northern latitudes, gives rise to a variable snow-line. In the Alps, the variation, from January to July, is 34°. Now the snow-line at the equator remains throughout the year at 15,800 feet; at the latitude of New York it is only one half of this. Therefore, to bring the snow-limit down to sea-level would require excessive cold†. But this more than polar reduction of temperature, and the uniform climate, would destroy the conditions necessary for the manufacture of the glacier, which must be constantly fed; and the supply depends on an abundant snow-fall, and this, again, on humidity. But an intense unchanging winter would be a dry one. Besides, if a snow-field does not attain a temperature higher than zero, it can never become a glacier; for the particles are as incoherent as sand‡.

Moreover, if formed, we doubt its ability to move. The extraordinary unbroken winter would prevent all movement; for this depends on repeated accumulations of snow and ice at the high sources, and on a change of seasons. All theories of glacier movement are based on the periodical partial liquefaction of the surface. The Alpine glaciers move twice as rapidly in summer as in winter. Then, too, the slope is insufficient. Forbes says a glacier must have an angle of 3° or

* Rounded and angular quartz-pebbles cemented with ferruginous loam are seen in the Pebas district.

† In Europe the most southern glacier which comes down to the sea is on the coast of Norway, lat 67°.

‡ According to Hopkins, if blocks on the Jura were transported from the Alps by the agency of ice, the Alps must have been at least 6000 feet higher than at present. But the lower the latitude, the higher the elevation needed. Who will estimate the altitude necessary to send an Andean glacier to the Atlantic?

4° *. But between Pebas and Pará, a distance of 1600 miles, the slope is only 8′ 5″, or about 2½ inches per mile; and from the tip-top of the Andes to the Atlantic the inclination is 6′ 30″. We conclude, therefore, that if a sheet of ice ever spread from Cotopaxi to the mouth of the Amazon, it remained there, immovable as the mountains.

But difficulties lie beyond this. As the length of a glacier depends greatly upon the speed with which it travels, it will be short in proportion as the angle of the slope is diminished. And, further, suppose the ice-sheet formed and moving, what would be its flow? Even if its rate equalled that of the Mer de Glace, a boulder from the Andes would be over 20,000 years in reaching the Atlantic; but when we consider its feeble slope, and its retardation by the constant trade-winds, we may wonder if it ever completed its journey. Yet this Agassiz glacier is represented as doing a greater amount of work than the high-latitude glaciers, grinding up and covering the vast basin with 800 feet of detritus, "the most colossal drift formation known." And, again, all the slope of any consequence lies between the axis of the Andes and Pebas, a distance of 450 miles. In this abrupt descent (35 feet per mile) it must receive momentum to carry it over an almost level plain of 1600 miles. Why did it not plough up the silt, creating linear lakes like Como and Maggiore, which radiate at right angles to the strike of the Alps? Yet there is no appearance of excavation. The lagunes of the Napo are shallow ponds.

4. The existence of such a continental glacier at the equator would profoundly affect the life-history of the globe. As Newberry says, "Nearly all the fossil plants and mollusks of the strata deposited immediately anterior to the glacial epoch are undistinguishable from species now living in the same region"†. If a mantle of ice ever covered Amazonia, undoubtedly it had lateral branches descending the valleys of the Orinoco and Paraguay: there is a close similarity of the formation in these valleys to the Amazonian clay, which has resulted, we think, from a contemporaneousness, if not identity, of origin; and so low is the watershed, especially on the north, that the two river-systems are joined by natural canals‡.

* The average slope of the Mer de Glace is 14°, that of the Greenland glacier 11°.

† In the opinion of De Candolle, subscribed to by Gray as likely, the greater part of the existing species of plants are older than the present configuration of our continent.

‡ The Casiquiari is only 400 feet above the sea, or about 200 above the centre of the Amazon basin.

The glaciation of the whole earth at the same time is absurd, on biological and hydrological grounds: if, therefore, an equatorial ice-period occurred before or after the ice-period of the high latitudes, we must imagine the temperate regions converted by a change of climate into a conservatory for the rich and peculiar life in the tropics—which is an unwarrantable assumption. Polar types are now living in the intertropical oceanic area; so that their occurrence in any marine deposit is no evidence *per se* of the general extension of glacial action into tropical regions. And we may add that the almost total absence of typical North-American plants in the highlands of the West Indies and on the Andes of the equator does not favour the theory of a glacial migration.

No continent has such a simple geological structure as South America. The monotony of its vast expanses is in strong contrast with the complexity of Europe: witness the unparalleled extension of gneissic rocks from the Orinoco to Paraguay, the long, compact range of the Andes, so eminently porphyritic, and the extraordinary continuity and uniformity of the Llanos, Amazon, and Pampa deposits of ochraceous sandy clay. Yet we have much to learn before it will be wise to speculate on the geological history of South America. Darwin and Hopkins have given us sections across the Cordilleras; and it is much to be regretted that Professor Hartt has failed to give us a physical map, with geological sections and reliable altitudes. We need a careful section from Rio to Pará, and another from Manáos to the mouth of the Orinoco. Barometrical measurements are indispensable; but, so far as we know, the only consecutive observations with a mercurial barometer across the continent are those made by the writer in 1867*.

It is probably safe to say this much:—that South America began with the tablelands of Guiana and Brazil†; that the subsequent upheaval of the Andes left estuary friths now marked by the three river-systems‡; that the Andes did not reach their present altitude until after the deposition of the Amazon formation, though it was a slow movement in mass, for the beds are nowhere unequally tilted or dislocated§; that

* Published in the 'American Journal of Science,' Sept. 1868.

† Bates has shown that the geographical distribution of insects indicates that Guiana was formerly an island.

‡ The sediments from these straits near the ocean would have a purely marine character; and Hartt observes that the clays and sandstones on the coast tie in with those of the Amazon.

§ This certainly follows, if the Pebas and Pichaua shells prove to be early Tertiary. The clay-beds ascend the eastern slope beyond the village of Napo, which stands 1400 feet above Pará, and in long. 77°. The red

the archipelago on the north was formerly united to the southern continent, and that it has since been an area of subsidence*; and that simultaneously with this subsidence was created the low watershed which now separates the Amazon and Caribbean waters.

XXXVII.—*On* Acanthopholis platypus (*Seeley*), *a Pachypod from the Cambridge Upper Greensand.* By Harry G. Seeley, F.G.S., St. John's College, Cambridge.

[Plate VII.]

There is no period in English geology in which the rocks themselves have not furnished evidence of the proximity of land to what are now our coasts. Occasionally they prove the present land and the past lands to have in part included each other; and in between these periods of similar altitude the depression is rarely if ever so profound or wide-spread as to remove the land to a distance too great to be measured approximately in miles by the evidence from the distribution of its detritus. But when the stratigraphic teaching becomes difficult to read or unravel in reasoning, then the fossils come to hand, in a rough way cut the knot that could not be untied, and invest the subject with new interest in the distribution of life; for sea-life, land-life, and river-life are in the main so different from each other, that they give evidence of the extent of strata and of the causes which limited them which are second only in usefulness to the lithological and petrologic facts. Among such obscure problems, but for its fossils, would have been the history of the Cambridge Upper Greensand—a mere junction-bed between the Gault and the Chalk; but the fossil fruits, the sea-birds allied to *Colymbus* and the penguins, the flocks of aërial quadrupeds (Ornithosaurs), the schools of Emydian Chelonians, and, lastly, the land-quadruped *Acanthopholis*, point to their home in a not distant country, of which the other deposits between the Gault and Chalk to the south and north help to tell the whereabouts and history.

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clay was not prominent on the Rio Napo till we reached long. 74° and an altitude of 550 feet, where there is a very high bank called *Puca-urcu* or *monte colorado*, containing lignite—"*una mina de carbon de piedra*," says Villavicencio. This interstratified lignite is traceable eastward as far as Tabatinga. Darwin says that the Pampean formation was accompanied by an elevatory movement.

* This is suggested by the South-American character of the West-Indian mammals and mollusks. There are palæontological reasons for believing (Proc. Acad. Nat. Sc. Philad. 1868, p. 313) that the Caribbean continent was not submerged before the close of the Postpliocene.